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Upper arm measurements of healthy neonates comparing ultrasonography and anthropometric methods

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Abstract

Objective: To compare measurements of the upper arm cross-sectional areas (total arm area, arm muscle area, and arm fat area of healthy neonates) as calculated using anthropometry with the values obtained by ultrasonography. *Materials and methods*: This study was performed on 60 consecutively born healthy neonates: gestational age (mean±SD) 39.6±1.2 weeks, birth weight 3287.1±307.7 g, 27 males (45%) and 33 females (55%). Mid-arm circumference and tricipital skinfold thickness measurements were taken on the left upper mid-arm according to the conventional anthropometric method to calculate total arm area, arm muscle area and arm fat area. The ultrasound evaluation was performed at the same arm location using a Toshiba sonolayer SSA-250A®, which allows the calculation of the total arm area, arm muscle area and arm fat area by the number of pixels enclosed in the plotted areas. Statistical analysis: whenever appropriate, parametric and non-parametric tests were used in order to compare measurements of paired samples and of groups of samples. *Results*: No significant differences between males and females were found in any evaluated measurements, estimated either by anthropometry or by ultrasound. Also the median of total arm area did not differ significantly with either method ($P = 0.337$). Although there is evidence of concordance of the total arm area measurements ($r = 0.68$, 95% CI: 0.55–0.77) the two methods of measurement differed for arm muscle area and arm fat area. The estimated median of measurements by ultrasound for

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arm muscle area were significantly lower than those estimated by the anthropometric method, which differed by as much as 111% ($P < 0.001$). The estimated median ultrasound measurement of the arm fat was higher than the anthropometric arm fat area by as much as 31% ($P < 0.001$). *Conclusion*: Compared with ultrasound measurements using skinfold measurements and mid-arm circumference without further correction may lead to overestimation of the cross-sectional area of muscle and underestimation of the cross-sectional fat area. The correlation between the two methods could be interpreted as an indication for further search of correction factors in the equations.

Keywords: Anthropometry; Skinfold thickness; Ultrasound; Upper arm areas

1. Introduction

In recent years, upper arm cross-sectional areas have been widely used as a simple, non-invasive and inexpensive method for assessment of the nutritional status of adults and children [1,2]. Standards for full-term and preterm neonates have also been reported recently [3,4]. These values are extrapolated from equations derived from mid-arm circumference (MAC) and tricipital skinfold thickness (TSF) [1,3,5]. It is not clear, however, how the conventional assumptions made in these calculations may stand compared to real time images of the arm cross-section. For the calculation of the arm muscle area, the conventional assumptions are that: (1) the mid-arm is cylindrical; (2) the subcutaneous fat is a concentric ring evenly distributed around the muscle; (3) that fat thickness is half the TSF; (4) that the muscle compartment is circular; and (5) that the muscle includes the humeral diameter. Any variation in bone diameter is not taken account [1,3,5]. Possible source of error using conventional assumptions is the variable tissue compression relative to differences in the skin tension when measuring TSF [6].

This study was designed to compare the upper arm cross-sectional areas of healthy neonates as measured by anthropometry with the values obtained by ultrasonography, a potential real time imaging method for assessment of arm areas in this age group.

2. Materials and methods

This study was performed on 60 neonates consecutively born at Dona Estefânia Maternity Hospital, after informed parental consent was obtained. Only full-term newborn infants with a birth weight of more than 2500 g, Apgar score more than 6 at 5 min, and with no detectable malformation were included in the study. Gestational age, birth weight and sex were recorded. To avoid inter-observer variability [7], all anthropometric measurements were carried out by a single trained observer (LPS). Measurements were taken within 24 h of birth on the left arm mid distance between the tip of acromion and the olecraneon process. The arm was always held extended. MAC was measured to the nearest millimeter using a plastic flexible non-extendible tape. The measured site was marked with a pen. TSF was evaluated using a Harpenden calliper at the same marked level of the extended arm. Measurements to the nearest 0.1 mm were made 60 s after application of the calliper, exerting a pressure of 10 g/mm^2 of contact surface area [8]. All anthropometric measurements were made in triplicate, and the results averaged. Cross-sectional arm area (AA), cross-sectional arm muscle area (AMA) and cross-sectional arm fat area (AFA) were calculated from TSF and MAC using conventional assumptions [1].

The ultrasound study was performed in all neonates using a Toshiba sonolayer SSA-250A®, using a mechanical SM-708A® sectorial probe of 7.5 MHz with an incorporated water cushion. The ultrasound examination was performed within 6 h of anthropometric assessment by a single operator experienced in pediatric examinations (JVG). The infants were placed in the supine position and the left arm was kept in an extended position slightly away from the body, and secured in such a way that no external pressure was exerted.

Close attention was given to the study protocol for obtaining a single transverse ultrasound view of the mid arm. To prevent any appreciable deformation of the arm image, it was established that the probe should never be applied to the posterior part of the arm. In the newborn, compression of subcutaneous tissues may deform the image, potentially changing the measurements. This deformation was minimized by applying the probe with the least possible pressure on the anterior part of the arm, thus reducing the probability of error. In order to achieve a near optimal image of the newborn’s arm, a water cushion was adapted to the probe. It was found to be an essential modification of the technique to achieve the best transversal, well defined view of the limits of the tissues involved.

The probe was applied on the anterior part of the left upper arm at the same level of the anthropometric measurements, in the location previously marked. The probe was positioned perpendicular to the long axis of the upper arm to obtain a transversal plane. Using electronic callipers built in the ultrasound equipment, measurements were taken of both the total area of that section of the arm and of the area which included the muscular tissue and the humerus. In this set of newborn infants, the authors established that the cone of posterior acoustic shadow created by the transversally cut humerus of the neonate was not sufficiently intense to prevent the ultrasound imaging of the posterior structures. A single plane transversal cut view of the arm allowed us to perform the various measurements to be obtained (Fig. 1). In the Toshiba sonolayer SSA-250A® the calculation of the areas was made by the number of pixels enclosed in the plotted areas (Fig. 1A–C). The reproducibility of the ultrasound measurements was tested in a separate sample of 16 healthy newborn infants. Statistical analysis of four consecutive measurements was used as the standard. The coefficients of variation of the measurements obtained for each variable were analyzed. Based on the Toshiba sonolayer SSA-250A® technical information, the systematic error was established at 6%. The maximum measurement error was estimated to be as much as twice the systematic error. In fact, the mean of the coefficients of variation obtained ranged from 1.4% (SEM = 0.2%) for the mid arm circumference to 3.4% (SEM = 0.6%) for the arm muscle area, clearly acceptable for the purpose of these measurements (data not shown).

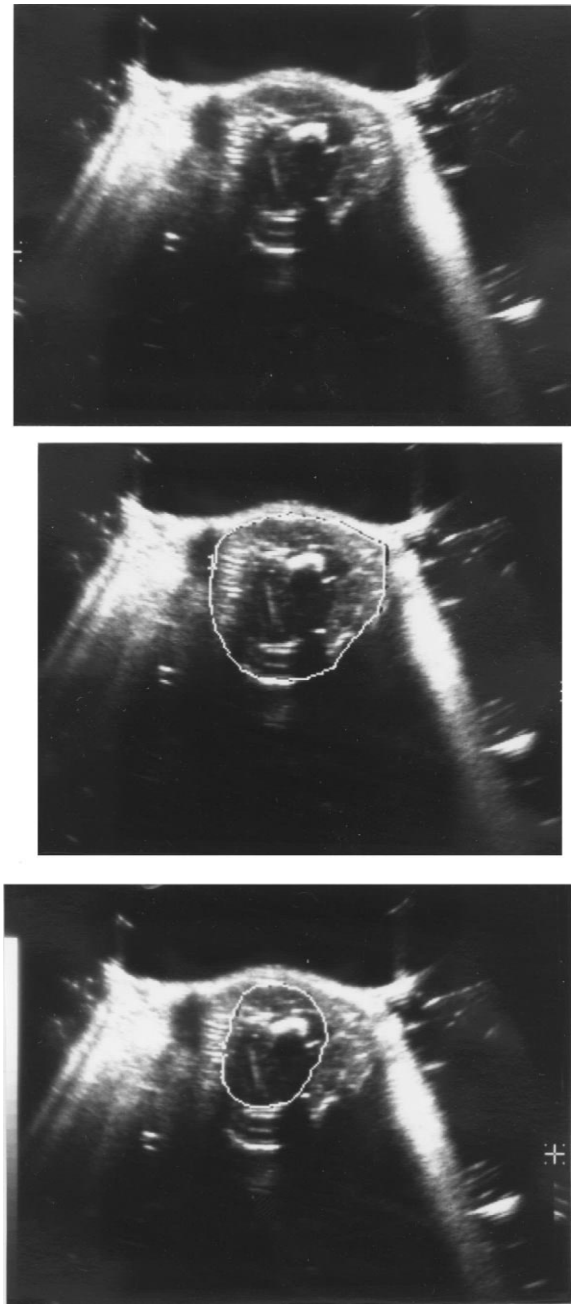

Fig. 1. Mid-arm cross-sectional ultrasonic view. (A) Plot of the mid-arm circumference obtained in the ultrasonic view regarding the calculation of the arm area. (B) Plot of the exterior limits of the muscular tissue obtained in the ultrasonic view regarding the calculation of the arm muscle area. (C) Diagram of A) and (B): UMAC, mid-arm circumference; UAA, arm area; UMMC, mid-muscle circumference; UAMA, arm muscle area (includes bone); arm fat area, UAA *minus* UAMA.

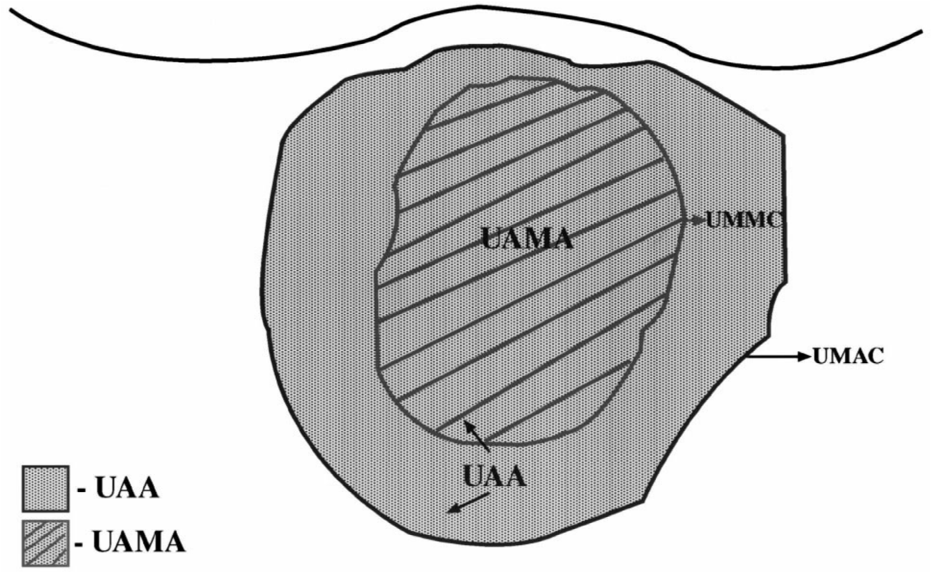

Fig. 1. (*continued*)

Statistical analysis was performed using the Stata 4.0 software (Stata Press, TX, USA 1995). Each measurement was analyzed by central tendency measures (means and medians), and dispersion measures (standard deviation, minimum, maximum and coefficient of variation). The central tendency results were compared according to the method of measurement (anthropometric or by ultrasound) and sex. Normality distribution was tested by Shapiro–Wilk test in order to apply the most appropriate test as follows: (1) in the case of data being normally distributed, *t*-test for paired samples was used when measurement methods were compared, and *t*-test for independent samples was used when sex was compared. (2) For data non-normally distributed we used the Wilcoxon test for paired samples and the Mann–Whitney test when measurements by sex were compared.

Concordance correlation coefficients [9] and its 95% confidence intervals (95% CI) were determined for each parameter, and the Bland and Altman approach [10] was followed in order to better define the limits of concordance.

A $P = 0.05$ or less was chosen as the level of statistical significance.

3. Results

The 60 healthy neonates studied had a gestational age of (mean$\pm$SD) 39.6$\pm$1.2 weeks and birth weight of 3287.1$\pm$307.7 g. The sample included 27 male (45%) and 33 female (55%) infants.

No significant differences between males and females were found in relation to all measurements studied: TSF, and MAC, AA, AMA and AFA assessed either by

Table 1
Tricipital skinfold thickness (mm)

	Total	Males	Females
Median	3.4	3.4	3.4
Mean	3.5	3.4	3.6
SD	0.6	0.5	0.8
CV (%)	17.1	14.7	22.2
Minimum	2.4	2.6	2.4
Maximum	5.4	4.4	5.4

anthropometry or by ultrasound. As an example, the distribution of TSF is represented in Table 1.

In contrast to the conventional assumptions of the anthropometric method, cross-sectional ultrasound shows that the mid-arm is not circular, but elliptical, and that the subcutaneous layer of adipose tissue is markedly asymmetric. The fat thickness over the triceps is considerably greater than over the biceps, as one could have expected. The muscle compartment does not form a circle and is variable in shape, resembling a ‘clover leaf’ in the majority of subjects.

An attempt was made to determine the agreement limits according to the approach of Bland and Altman. However, the distribution of anthropometric and ultrasound sample differences for MAC, AA and AFA, but not AMA, did not pass normality tests, and the logarithmic transformation did not produce reliable results. In this sense, the agreement between the two methods of measurement was evaluated through scatterplots and its concordance by correlation coefficients.

Both MAC assessed by anthropometry (AMAC) and MAC assessed by ultrasound (UMAC) (Table 2) follow a normal distribution. Values of AMAC are significantly lower than UMAC ($P < 0.001$). A minimal but definable compression of tissues may account for smaller arm circumference measured by tape. Intuitively the tape measure of the arm circumference should be the most accurate. Concordance correlation between the two measurement methods for MAC ($r = 0.64$, 95% CI: 0.50–0.75) is depicted in Fig. 2.

The Wilcoxon test was used to evaluate the differences between the two methods for assessment of AA, AMA and AFA, because the results of the ultrasound

Table 2
Mid-arm circumference (mm)

	Anthropometry			Ultrasound		
	Total	Males	Females	Total	Males	Females
Median	104	104	103	109	110	105
Mean	104.4	104.8	104.0	108.5	108.8	108.2
SD	6.5	4.9	7.6	10.3	6.9	12.5
CV (%)	6.2	4.7	7.3	9.5	6.3	11.6
Minimum	88	95	88	91	94	91
Maximum	118	118	116	136	119	136

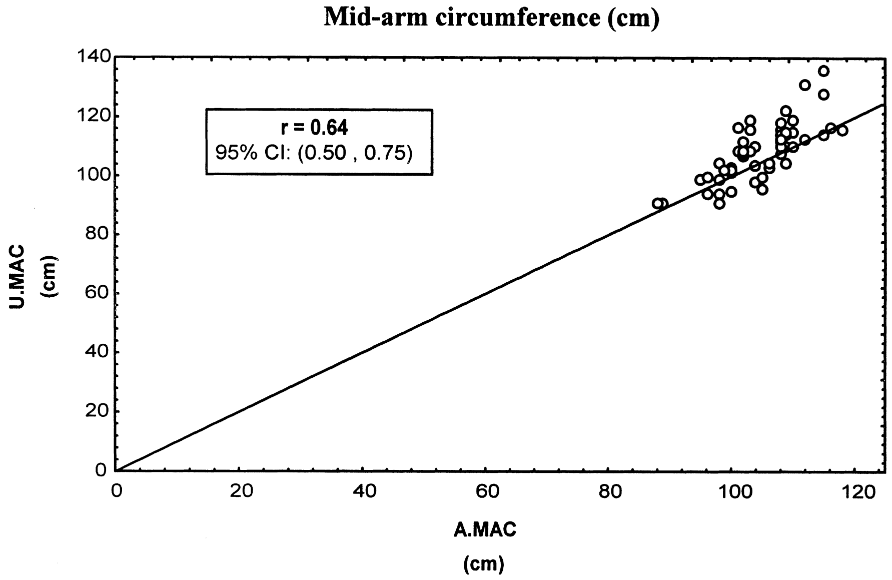

Fig. 2. Concordance correlation between mid-arm circumference (MAC) measured by anthropometry (AMAC) and measured by ultrasound (UMAC).

measurement of AA (UAA), AMA (UAMA), and AFA (UAFA) were not normally distributed.

The median of AA does not differ significantly ($P = 0.337$) if assessed by ultrasound or by anthropometry (AAA) (Table 3). The concordance correlation between the two measurement methods for AA ($r = 0.68$, 95% CI: 0.55–0.77) is represented in Fig. 3.

The median of AMA measured by ultrasound differs significantly from that measured by anthropometry (AAMA) ($P < 0.001$) (Table 4). AAMA overestimates muscle area when compared to the UAMA by as much as 111%. The concordance correlation between the two measurement methods for AMA is ($r = 0.04$, 95% CI: 0.02–0.06) and is represented in Fig. 4.

Table 3
Arm area (mm^2)

	Anthropometry			Ultrasound		
	Total	Males	Females	Total	Males	Females
Median	861	861	844	896.5	904	849
Mean	869.4	875.5	864.6	892.6	888.0	896.3
SD	107.2	82.4	124.9	170.2	110.6	208.5
CV (%)	12.3	9.4	14.4	19.1	12.5	23.3
Minimum	616	718	616	617	672	617
Maximum	1108	1108	1071	1410	1060	1410

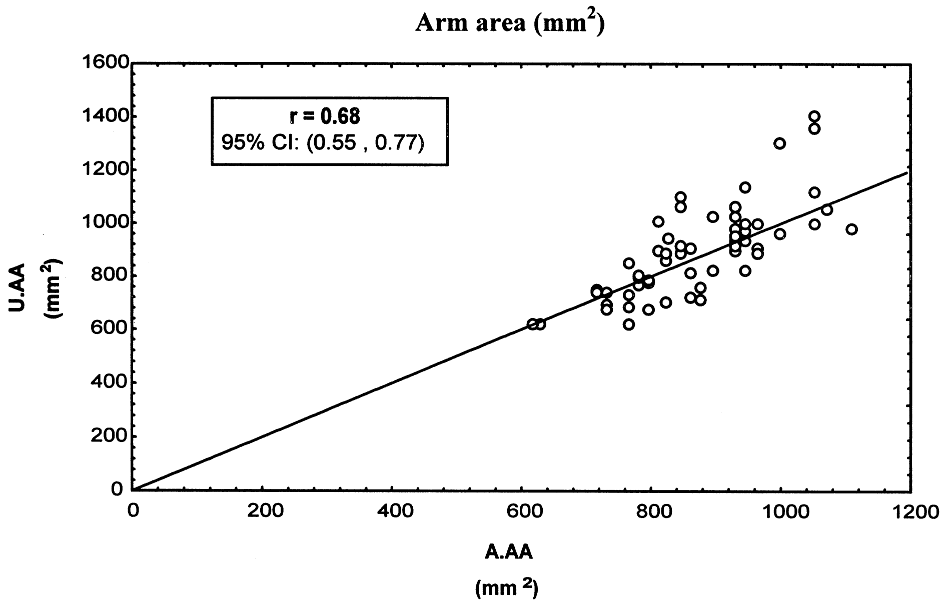

Fig. 3. Concordance correlation between arm area (AA) measured by anthropometry (AAA) and measured by ultrasound (UAA).

In contrast to the measurements of muscle areas, the median of AFA is significantly less ($P < 0.001$) if it is assessed by ultrasound compared to the estimated areas using anthropometry (AAFA) (Table 5). The AAFA underestimates UAFA by 31%. The concordance correlation between the two measurement methods for AFA ($r = 0.04$, 95% CI: 0.03–0.05) is represented in Fig. 5.

4. Discussion

Some authors have argued that estimates of muscle and fat content of the arm based on MAC and TSF are not accurate. Real time image technology is likely to

Table 4
Arm muscle area (mm^2)

	Anthropometry			Ultrasound		
	Total	Males	Females	Total	Males	Females
Median	708	721	683	321.5	320	323
Mean	696.4	706.3	688.3	330.2	336.9	324.7
SD	80.5	66.5	90.6	77.4	70.0	83.7
CV (%)	11.6	9.4	13.2	23.4	20.8	25.8
Minimum	480	583	480	210	227	210
Maximum	906	906	888	598	553	598

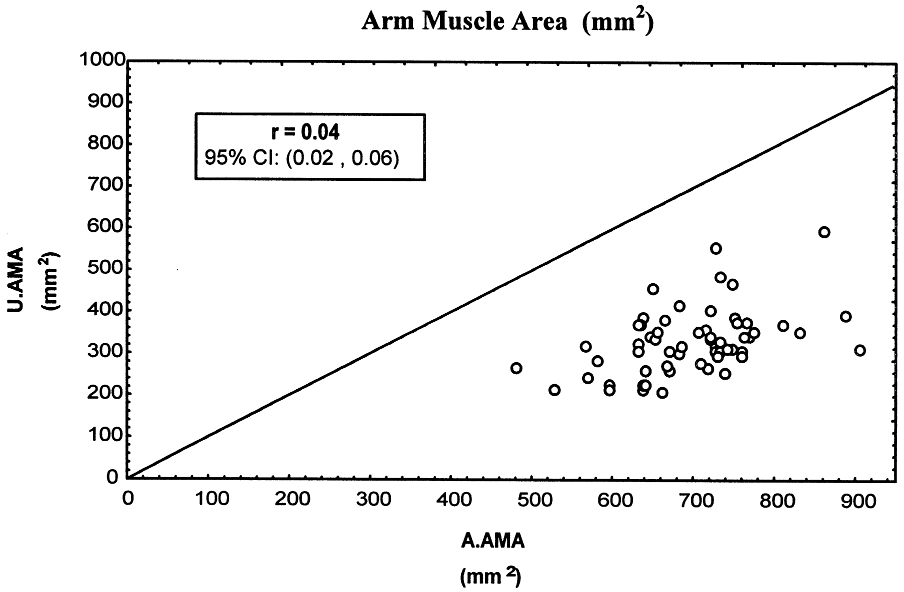

Fig. 4. Concordance correlation between arm muscle area (AMA) measured by anthropometry (AAMA) and measured by ultrasound (UAMA).

provide very accurate estimates of such measurements, but this technology may not be as readily available as a tape and calliper. It is important to recognize the sources of inaccuracy and correct them in the assessment of tissue contents of the arm based on simple measurements like MAC and TSF. It has been assumed that larger arms have disproportionately more adipose tissue than smaller arms [1,5]. Using these criteria, cross-sectional arm areas have been preferred by some authors [2,11,12], as they represent better estimators of the relative contribution of fat and muscle to the total arm area than MAC and TSF used alone.

Some studies have demonstrated that conventional assumptions in the calculations of cross-sectional areas of the mid-arm are not accurate enough to appropriately estimate tissue size. Heymsfield et al. [13] identified errors inherent in the anth-

Table 5
Arm fat area (mm^2)

	Anthropometry			Ultrasound		
	Total	Males	Females	Total	Males	Females
Median	167.5	169	165	556.5	564	554
Mean	173.1	169.2	176.3	560.8	551.1	568.7
SD	38.6	26.8	46.2	124.1	95.3	144.4
CV (%)	22.3	15.8	26.2	22.1	17.3	25.4
Minimum	102	122	102	352	387	352
Maximum	287	224	287	1059	704	1059

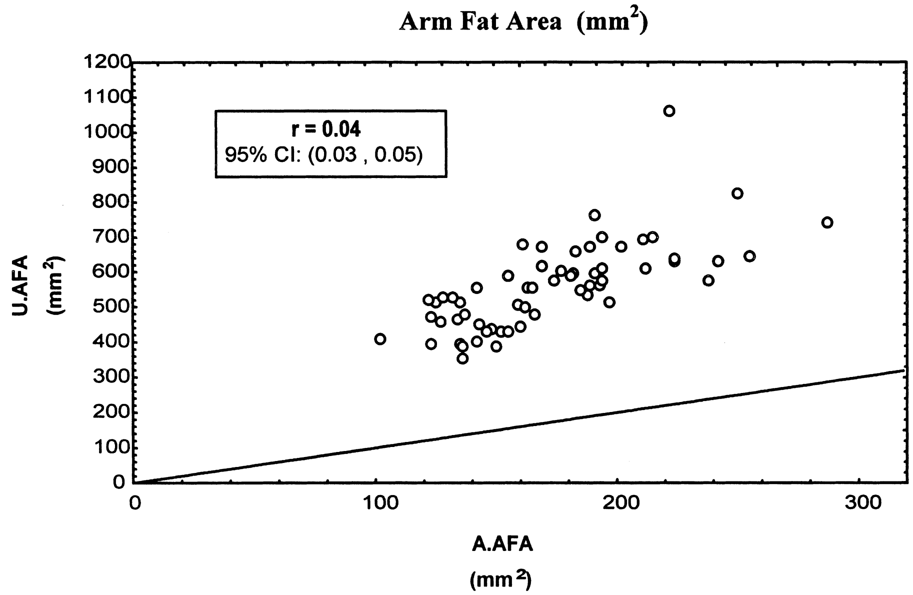

Fig. 5. Concordance correlation between arm fat area (AFA) measured by anthropometry (AAFA) and measured by ultrasound (UAFA).

ropometric method, using mid-arm computerized tomography scan performed in adults. In their study they found that the arm is elliptical and that in the majority of subjects the muscle compartment is rarely circular, rather resembling a ‘clover leaf’ as in our study. Furthermore, they concluded that the fat area model assuming an annulus of fat is not accurate enough. Instead, fat is asymmetrically distributed around the arm, with greater fat thickness behind the triceps than in front of the biceps. These results confirmed the findings of previous studies [14].

Another convention in the anthropometric method is to assume that the skinfold thickness is a measure of subcutaneous fat, assuming that the skinfold represents a double thickness of subcutaneous fat *plus* skin. The degree to which fat tissue and other tissues can be compressed during the TSF measurement may lead to an error [6]. The error may be predicted if every compression is done with the same pressure and time relationship [8]. The correction factor for better estimate of the cross-sectional areas of tissues has not been determined in newborn infants. It is apparent from the results of our study that, in order to make the conventional measurements based on MAC and TSF more accurate, there needs to be a constant factor to correct for tissue compression in the newborn, otherwise skinfolds will always underestimate actual thickness [6]. Therefore, according to our study, when uncorrected skinfold measurements and MAC are used to estimate cross-sectional mid-arm tissue areas, the assumptions lead to overestimation of the cross-sectional area of the muscle and underestimation of the cross-sectional fat area [6]. In neonates this effect may be more relevant, since differences in skinfold compressibility are influenced by many factors, such as differences in skin turgor related to nutritional status and hydration [6,8,15].

In the present study a possible source of error using ultrasound could be the cone of posterior acoustic shadow created by the transversally cut humerus. In the neonate this shadow was not sufficiently intense to prevent the ultrasound view of the posterior structures, allowing us to use the images for measuring the cross-sectional areas of the mid-arm in this age group. For ethical and economic reasons, the comparison of the measurements made by ultrasound with other real time imaging methods at the cutting edge of technology such as CT scan or MRI was not done in this study. Nevertheless, we were able to prove the reproducibility of the ultrasound method, which provides internal validity to our data. The differences between values derived from ultrasonic method compared with anthropometric method require re-definition of the variables involved in the calculations of cross-sectional areas based on MAC and TSF. Further studies are needed to define the factors (constants) that can be used to improve the estimate of cross-sectional areas of muscle and fat in the arm of neonates, a key element of nutritional assessment. Due to the inherent limitations of the ultrasonic technique we would recommend using the most accurate of imaging technologies currently available, magnetic resonance imaging, to determine the gold standard for these measurements [16].

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